VOLUME 81 SEPARATE No. 639

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

MARCH, 1955

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

ENGINEERING ADVANCEMENTS AT McNARY PROJECT

by Louis E. Rydell, A.M. ASCE, and
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POWER DIVISION

{Discussions open until July 1, 1955}

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

ENGINEERING ADVANCEMENTS AT McNARY PROJECT

Louis E. Rydell,[1] A.M. ASCE, and Glenn H. Von Gunten,[2] A.M. ASCE

SYNOPSIS

Now being completed on Columbia River between the states of Oregon and Washington is one of the world's outstanding power and navigation developments. McNary Lock and Dam, involving a construction expenditure of $287,300,000, will add 980,000 kilowatts of generating capacity to supply the Pacific Northwest's growing markets, and will create a 60-mile slackwater navigation pool constituting a major addition to the Columbia River navigable waterway. Located some 300 miles inland from the Pacific Ocean and accessible by barge navigation, this pool is already the site of several harbor developments serving the commerce of the large northwest grain producing region, the Columbia Basin Irrigation Project now coming into production, and the Tri-City area of Pasco, Kennewick and Richland, adjacent to the Hanford Works of the Atomic Energy Commission in the state of Washington. The project is a principal unit in the comprehensive plan for development of Columbia River water resources[3] as set forth in House Document 531, 81st Congress, 2nd Session. Due to its magnitude and complexities the McNary project has presented many challenges to the engineering profession in its planning, design and construction. Engineering advancements include the highest single lift lock in the world; special features of the dam, spillway and powerhouse structures, and hydro-electric power generating units; new developments on fish passage facilities; and unusual construction accomplishments. This paper, in addition to general background information and project description to enable the reader to visualize the purposes and functions as related to the comprehensive regional plan, presents discussions of project features largely confined to the more significant engineering problems encountered in the basic design and accomplishment of the McNary project.

INTRODUCTION

McNary Lock and Dam, named in honor of the late U. S. Senator Charles L. McNary of Oregon, was authorized by Congress on 2 March 1945, for the primary purposes of navigation and power production with incidental irrigation and recreation benefits. Construction was begun in May 1947, and is scheduled for completion in December 1956. The navigation lock was placed in interim operation in late 1950. The reservoir pool was raised to its full elevation in December 1953 and the first McNary power unit was placed in operation

1. Chf., Planning and Reports Branch, Walla Walla Dist., Corps of Engineers, Walla Walla, Wash.
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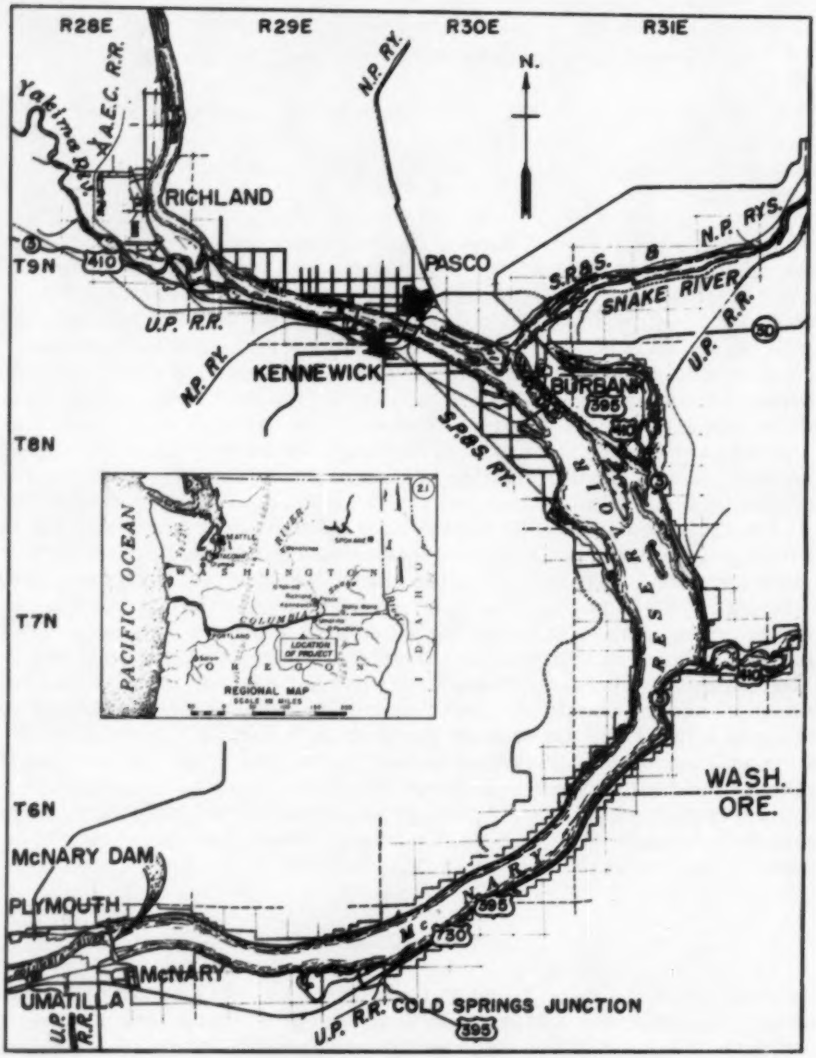
3. Reference, "Comprehensive Plan for the Columbia River" by William Whipple, Jr. with discussion by L. E. Rydell. Paper 2473, Vol. 116, 1951.



VICINITY MAP

SCALE IN MILES

5 0 5 10

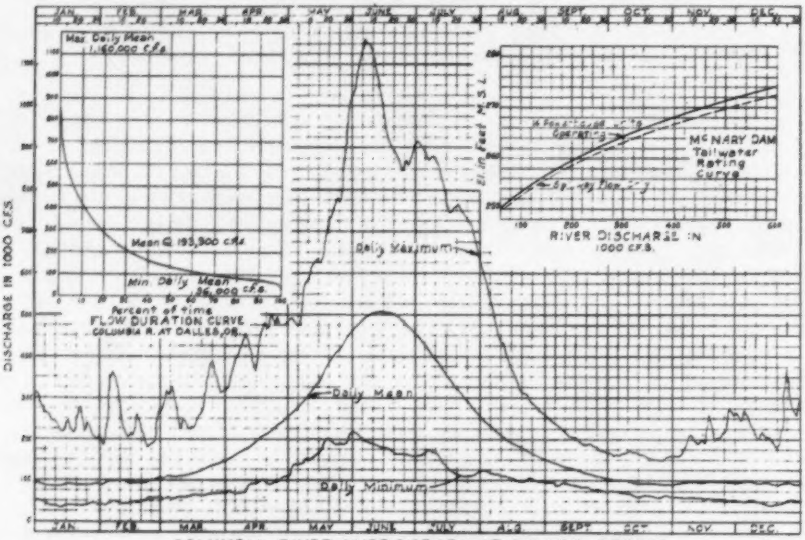
Fig. 1

on 6 November 1953. Five generators were in operation by September 1954 and one additional generator is scheduled to go on the line about every 90 days thereafter until the full capacity of 980,000 kw in 14 units is reached. The reservoir and general project location is shown on Figure 1.

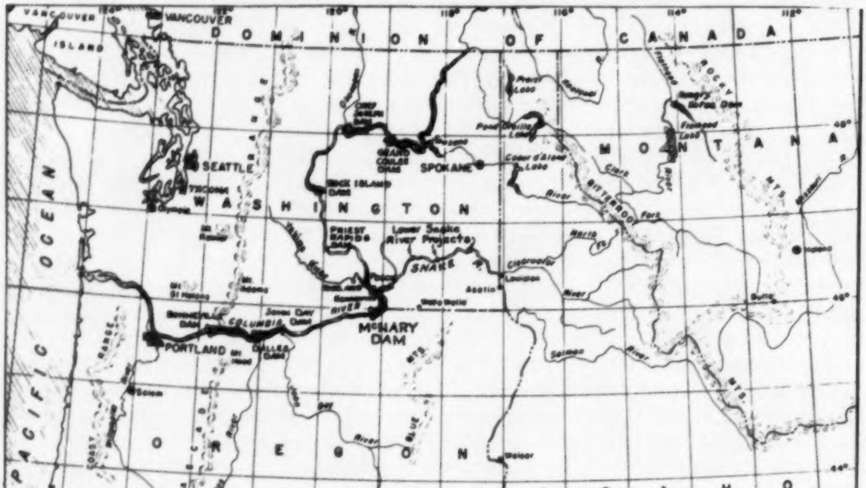
History

Umatilla Rapids, at the foot of which McNary Dam is now located, were among the most serious obstacles to early day navigation on Columbia River, and the eventual construction of a dam and lock was envisioned by navigators as early as the 1890's. Power development at Umatilla Rapids had been given consideration since the early days of the present century. The power potential of the average Columbia River flow of 190,000 c.f.s., about ten times that of the Colorado River at Hoover Dam, challenged the imagination, but the marketing of such a large block of power posed an insurmountable problem in those early days. The economic possibilities of utilizing this power for pumping of water to some 240,000 acres of irrigable lands adjacent to Columbia River was investigated by the Bureau of Reclamation in the 1920's. The development of a navigation-irrigation-power project was further investigated by the Corps of Engineers in 1928-32 and included in the basic plan for development of Columbia River recommended in 1932. Within two years actual construction was under way on two other units—Bonneville and Grand Coulee—of this plan. Because the large power potentials of the latter two projects were believed to be adequate to meet the needs of the Pacific Northwest for a long period to come, further studies by the Corps were directed primarily towards solution of the navigation problem in this reach of Columbia River and resulted in a tentative recommendation in 1937 to develop the Umatilla site by a relatively low navigation dam with power as an incidental feature.

Two factors developed between 1937 and the beginning of World War II to bring the power aspects of Umatilla Rapids into sharp focus. One was the completion of Grand Coulee Dam with its usable storage of 5,200,000 acre-feet capable of doubling the low water flow of Columbia River. A second factor was the startlingly rapid utilization of Grand Coulee and Bonneville power output by new industrial developments in the Northwest, including electro-metallurgical and electro-chemical industries, notably aluminum. Further impetus in this direction was provided by the industrial mobilization accompanying World War II. By 1942 it was evident that the full output of these dams, totalling about 2,500,000 kw installed capacity, would be fully utilized within a relatively few years. This development was particularly surprising to those who had anticipated difficulty in disposing of even the output of the first two 43,200 kw units at Bonneville. Largely through the prior efforts of the then deceased Senator McNary of Oregon, Congress gave recognition of this new situation in 1945 by authorizing the construction of a major dam at the Umatilla site, to be named McNary Dam. The authorizing act specified construction of the dam to provide a pool elevation of 340 feet above sea level if found to be feasible (studies described below were then under way), for the purposes of navigation, power and irrigation; disposition of the electric energy by the Secretary of the Interior through the Bonneville Power Administration; and, adequate provisions to be made in design, construction, and operation for the protection of anadromous fishes by affording free access to their natural spawning grounds or by other appropriate means.



COLUMBIA RIVER HYDROGRAPH AT DALLES, OREGON



REGIONAL MAP

SCALE IN MILES

50 0 50 100

Fig. 2

Columbia River Hydrology

Out of a total drainage area of 259,000 square miles at its mouth, the Columbia River above McNary Dam drains an area of 214,000 square miles including portions of the states of Oregon, Washington, Idaho, Montana, Wyoming, Utah and Nevada and the Province of British Columbia. This area extends from the Cascade Range on the west to Rocky Mountain Range on the east. Mean annual precipitation is 24.2 inches and varies from about 7 inches in the plains areas to 100 inches in some of the mountainous regions. While the intermediate region is generally semi-arid, moisture from the prevailing southwesterly winds is deposited in the form of snow in the mountainous headwater areas to the east and results in a much higher run-off from these areas. This snow, melting in the spring and early summer, is the principal source of Columbia River flow and accounts for the basically uniform stream flow pattern as indicated on Figure 2 for The Dalles station (which represents about 105% of the flow at McNary). High flows occur during the months of May through July, and low flows generally from October through March. The mean annual run-off is approximately 135,000,000 acre-feet and the long term average stream flow at McNary is 186,000 c.f.s. or 0.90 c.f.s. per square mile drainage area. Maximum flow of 1,200,000 c.f.s. occurred in June 1894, and the disastrous flood of May-June 1948 attained a peak discharge of 980,000 c.f.s. Minimum daily flow of 31,000 c.f.s. at McNary site occurred in January 1937. Approximate effects of regulatory storage constructed since that time and projected for future construction are illustrated below:

Regulation	Storage acre-feet	Discharge in C.F.S. Minimum day	Minimum month	Critical power period (Avg.)
Unregulated[1]	1	31,000	38,000	52,000
Present regulation[2]	9,280,000	-	76,000	86,000
Future regulation Phase "C"[3]	22,000,000	-	99,000	109,000
Future regulation Phase "D"[4]	41,000,000	-	-	123,000
Complete regulation[5]	500,000,000	-	-	186,000

1. Incidental regulation only by reservoirs operated for local control purposes as existing in 1937.
2. Grand Coulee 5,180,000 a.f.; Hungry Horse 2,960,000 a.f.; Albeni Falls 1,140,000 a.f.
3. Main control reservoirs recommended for relatively early construction.
4. System of secondary reservoirs considered for eventual construction.
5. Theoretical storage as effective at McNary, not practicable of achievement.

Economic Height of Dam

Power generation was one of the major factors entering into the determination of the optimum height of McNary Dam. This determination was not only an interesting problem of engineering economics, but one which involved a number of unusual factors. The lower pool limit was fixed at about elevation 310.5 by navigation requirements to pass the hazardous rapids in Columbia River and to provide slackwater to the mouth of Snake River. The resulting effective height of 62 feet would be comparable to that at existing Bonneville Dam. Beyond the desirability of providing navigable conditions to the Pasco-Kennewick-Richland area, no specific requirement existed as to the upstream extension of the pool on Columbia River. Priest Rapids, the next upstream

favorable dam site at river elevation 405, was far beyond practicable reach of McNary backwater. Hence the problem resolved itself into the economics of site development in the interests of power production, as restricted by increasing flowage costs for pool elevations above 310.5. Involved in the latter were two main line railroads (with three major bridges over Columbia and Snake Rivers) and an interstate highway, all paralleling the river on water grades; the small railroad town of Wallula; agricultural lands in the vicinity of Kennewick; and encroachment on the urban developments of the Tri-City area. All of these developments and contiguous improved areas were already subject in varying degrees to the hazards of major Columbia River floods, the greatest of which occurred in 1894. Backwater effects of the dam, as superimposed on the 1894 flood, accordingly became a controlling criterion. Five layouts of the dam, relocations and protective levees were made for pool elevations 310.5, 320, 330, 340 and 350, and cost estimates prepared therefrom. Corresponding computations were made of power production, navigation and other benefits for each height of dam. Comparison of annual costs with annual benefits showed that the greatest return per dollar invested would be obtained by construction of a dam to approximately pool elevation 345. The final decision, however, was complicated by other factors. Selection of favorable dam sites on Snake River matching the various Columbia River pool elevations was difficult of exact solution without extensive studies of specific sites and of combinations of dams to develop the lower 140 miles of that river as authorized by Congress. Other considerations included the desirability of limiting the head at McNary to not more than 100 feet in order to permit use of Kaplan type turbines with their favorable operating characteristics; expressed objections of fisheries interests to any dam having possibilities of interferring with the passage of migratory salmon; the adverse psychological effects that might be created by high levees in the upstream urban areas; and conversely the advantages of a higher pool level to reduce the natural flood stage fluctuations amounting to as much as 35 feet in these same areas. Consideration of all these factors involved a large measure of judgment and admittedly some degree of calculated risk; but the stakes were high. One foot of head at McNary Dam, developing an average of about 10,000 kw firm power during project life, was worth approximately $80,000 in revenues annually at the site and in excess of $175,000 at the market, with a capitalized value approaching $2,000,000 at the site, and had an intrinsic economic value to the region far in excess of those amounts. Final determination, based on consideration of all the above factors, was to develop the project to pool elevation 340 and eventual decision to install 980,000 kw. Compared to 420,000 kw installed capacity as originally proposed with pool elevation 310.5, the determinations resulted in approximately doubling the firm power capability of the Umatilla, now McNary, project.

Location and General Description

McNary project is one of ten existing and/or projected major dams on the main stem of Columbia River within the United States.[4] It is located 292 miles above the river mouth and 3 miles upstream from Umatilla, Oregon (Fig. 1). The reservoir provides some 61 miles of slackwater navigation extending 10 miles above the mouth of Snake River and to the cities of Pasco, Kennewick and Richland on Columbia River. The project consists essentially of a dam of 92 feet hydraulic height and 158 feet structural height, a spillway

4. See referenced paper by William Whipple, Jr.

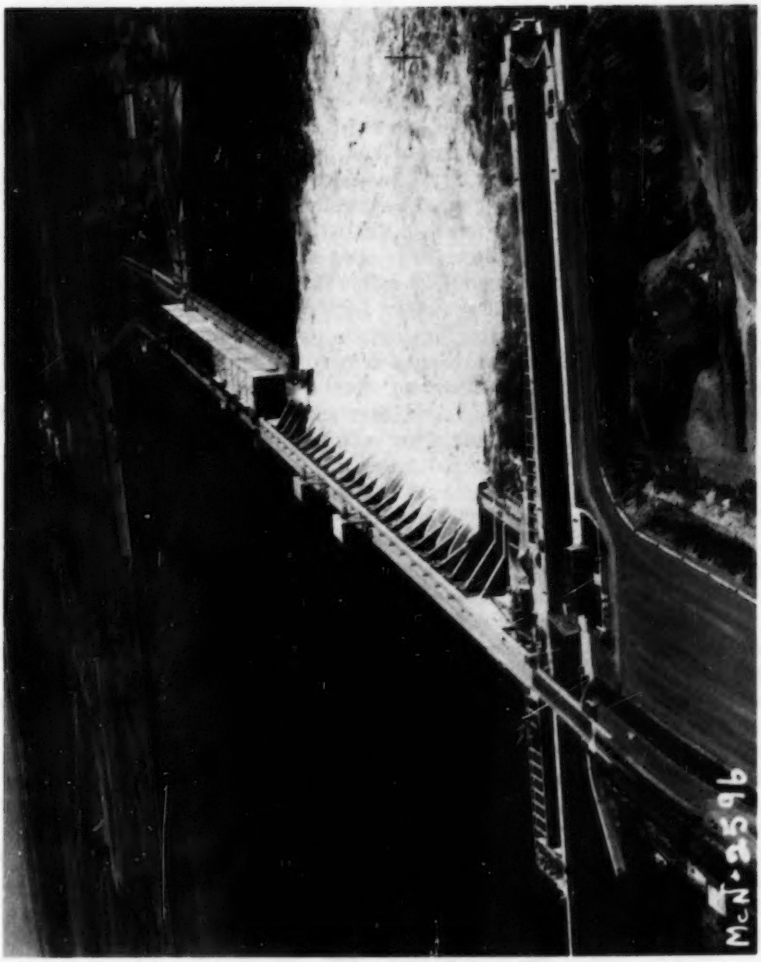


Figure 3 - McNary Lock and Dam

with a capacity of 2,200,000 cubic feet per second, a single lift 86 feet by 675 feet navigation lock, a 14-unit 980,000 kw power installation, extensive migratory fish passage facilities, and a levee system to protect the cities of Pasco, Kennewick and Richland, Washington. A photograph of the nearly completed dam is shown on Figure 3, a general plan on Figure 4 and typical sections of major structures in Figure 5.

Navigation Features

General

McNary project represents a major step in development of the Columbia-Snake River navigation system. With its 60-mile pool, the project comprises the upstream terminus of the present 340-mile Columbia River inland navigation route and its junction with the authorized 140-mile Lower Snake River project which will extend slackwater to Lewiston, Idaho. Tidewater and a deep draft open river navigation channel extends from Pacific Ocean up the Columbia to Vancouver, Washington at mile 107, and continues with an authorized 27-foot depth upstream to Bonneville Dam at mile 145. Bonneville project provides a 27-foot draft channel 48 miles farther to the site of The Dalles Dam, now under construction. Slackwater development of the remaining 287 miles will be provided by the latter project, in conjunction with McNary, and the authorized John Day and Lower Snake River projects.

Columbia River has been an important avenue of transportation since white men came to the Pacific Northwest a century and a half ago, and early settlers relied heavily on river transportation for both freight and passenger movement. Today the deep draft lower 107 miles of Columbia River is one of the most heavily travelled inland waterways in the nation, carrying some 20,000,000 tons sea-going and 30,000,000 tons total commerce annually and serving principally the Portland-Vancouver-Willamette Valley and the Longview areas. Navigation on the upper river (above Vancouver), which averaged about 50,000 tons annually prior to completion of Bonneville Dam in 1938, today has increased to over 1,000,000 tons annually. Upon realization of the navigation system by completion of The Dalles Dam and construction of the authorized John Day and Lower Snake River projects, traffic is expected to increase to 5 or 6 million tons annually. Of this commerce McNary Lock and Reservoir is expected to serve about 3.5 million tons annually.

Prior to construction of McNary Lock and Dam, navigation through and upstream from Umatilla Rapids was impeded by restricted clearances and extremely swift flows. Channel widths were limited in several reaches from 100 to 200 feet and channel depths were shallow, often only 5 to 6 feet during low water. McNary project has eliminated those problems within the reservoir by providing slackwater and a wide channel throughout the pool. The 92-foot single lift lock at McNary has a net clear width of 86 feet, length of 675 feet, minimum depth of 14 feet over the upper sill and 12 ft. depth over the lower sill. Upon construction of the downstream John Day Dam the minimum depth over the lower sill will be 16 feet, sufficient for ocean going barges to ascend the Columbia River. The 92-foot hydraulic lift under minimum anticipated flow of 43,000 c.f.s. is the highest single lock lift in the world, surpassing the maximum lift at Fort Louden by 12 ft. and Donzere Moudragon lock by 6 feet. The walls are founded on rock and are 128 feet high with top at elevation 348 which is eight feet above normal maximum pool elevation. Generous approach guard wall lengths of 1400 ft. upstream and 1500 ft. downstream, moorage basins and 250 by 6000 ft. lock approaches provide safe navigation conditions.

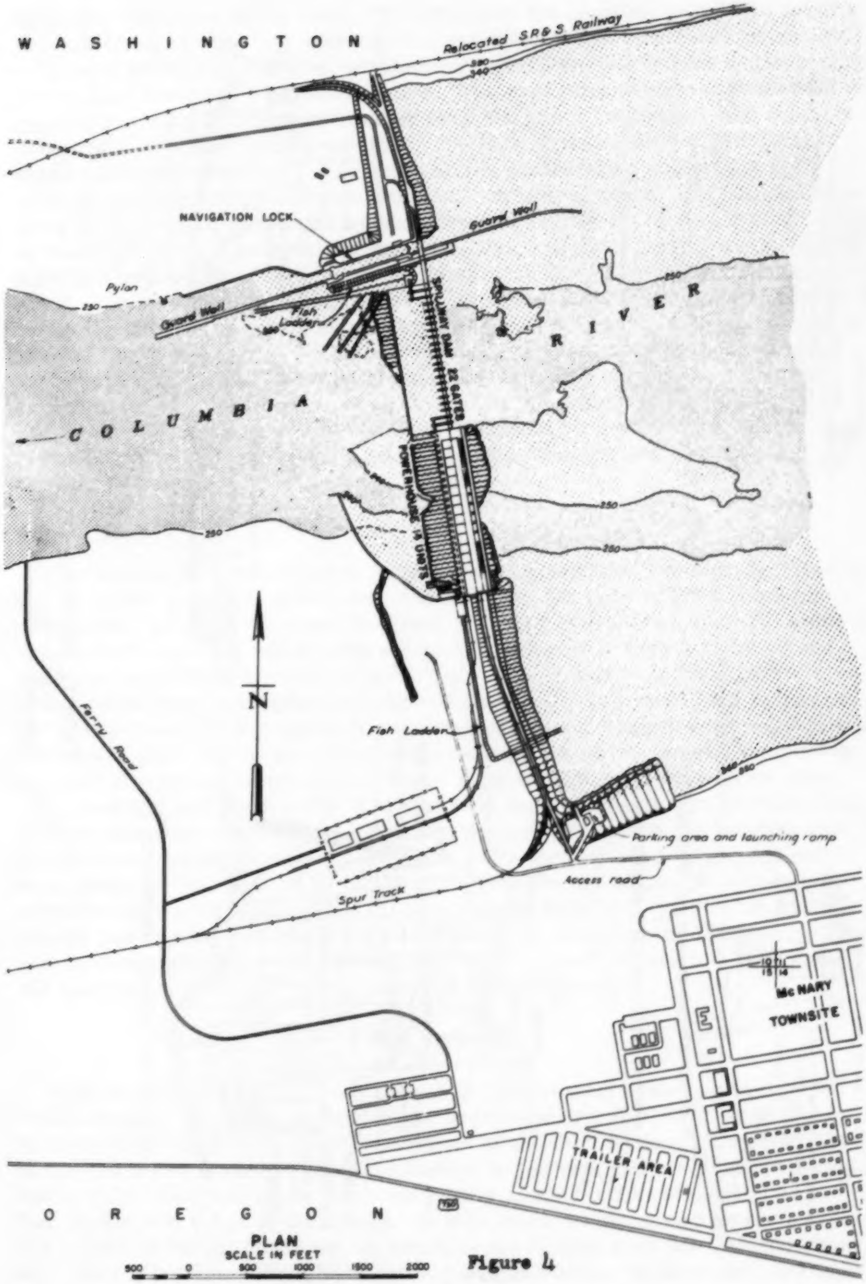

WASHINGTON
Relocated SP&S Railway
NAVIGATION LOCK
Guard Wall
Pylon
Fish Ladder
SPILLWAY DAM 22 GATES
RIVER
COLUMBIA
POWERHOUSE 14 UNITS
N
Ferry Road
Fish Ladder
Parking area and launching ramp
Access road
Spur Track
McNARY
TOWNSITE
TRAILER AREA
OREGON
PLAN
SCALE IN FEET
500 0 500 1000 1500 2000

Figure 4

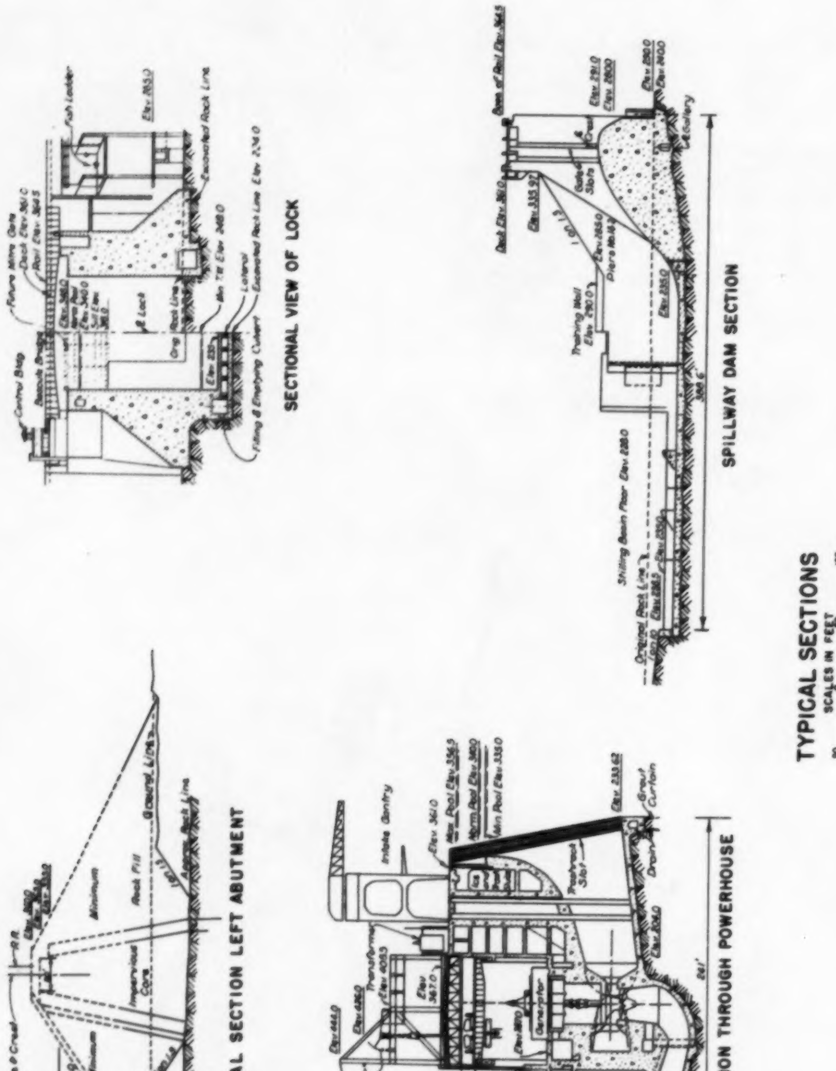

TYPICAL SECTION LEFT ABUTMENT
SECTIONAL VIEW OF LOCK
SECTION THROUGH POWERHOUSE
SPILLWAY DAM SECTION
TYPICAL SECTIONS
SCALES IN FEET

Figure 5

Hydraulic System

A water volume in excess of 120 acre-feet is involved in each filling and emptying operation of the lock. The necessity for handling this large volume in a minimum of time and without creating undesirable turbulence presented a difficult problem. The plan adopted represents an outstanding example of recent lock design in the United States. The hydraulic system is somewhat similar to that of MacArthur Lock at Sault St. Marie, Michigan, and consists essentially of a longitudinal culvert in the lock walls serving a distribution system of transverse lateral culverts on the center third of the lock floor each of which is provided with a series of horizontal ports. Filling and emptying of the lock is controlled by two reversed tainter valves, 11 feet wide by 12 feet high in each lock wall or culvert. The wall culverts are designed with a soffit elevation eight feet below minimum tailwater to provide submergence of the downstream face of the valves at all times. Open valve pits extending to the top of the lock walls act as surge chambers during filling and emptying operations. Each pair of filling and emptying valves are operated simultaneously by interconnected electrical control. At maximum lift the filling and emptying time is 16 minutes each. Hydraulic conditions in the system are very good and compare closely to those indicated by model tests. Turbulence at the intake portal, in the lock chamber and in the downstream approach channel is slight.

Miter Gates

The downstream miter gates have an overall height of 106 feet (believed to be the tallest hydraulic gates ever constructed) and span of 92' 8" between abutments. In order to carry the great resulting hydrostatic load, the gates are arched in plan to act as a three-hinged arch with a radius of 53' 6" and each leaf subtending an angle of 60°. Each gate leaf is supported at the base by a conventional hemispherical pintle bearing of nickel steel, and hinged at the top by means of a gudgeon linkage connected to a flexible anchorage in the lock wall. Gate leaves are all welded construction which permitted shop fabrication in sections consisting of 3 or 4 ribs, welded together with adjacent skin plate and end posts. The stressed skin design concept was used for reasons of economy with the gate skin plate designed for combined bending and compression stress without intercostals. The largest shop fabricated units were about 12 feet high by 53 feet long. The economy of this arch design is indicated by the fact that each gate leaf weighs "only" 344 tons or about 150 pounds per square foot of net projected area, as compared to 555 tons or 290 pounds respectively for the conventional (non-arched) Bonneville Dam gates 101 feet high and 76 feet wide, typical of similar gates.

Power Features

With its tributaries, Columbia River is the greatest power stream in the United States. About 38 percent of the hydro-electric potential of the United States lies in the Pacific Northwest, most of which is in the Columbia Basin. In the 750 miles from the Canadian border to the sea, the main stream has a fall of 1,290 feet, and mean flows vary from 104,000 c.f.s. at Grand Coulee Dam to 260,000 c.f.s. at the mouth. In this reach ten dams and power plants are proposed for development, of which Grand Coulee near the Canadian border, Rock Island in central Washington, and Bonneville at tidewater, are completed; Chief Joseph, McNary and The Dalles are under construction; and four

others are projected. Major power potentials exist on various tributaries, and also on Columbia River in Canada. Federal development within the U. S. of some 10,800,000 kw power was recommended in the 1948 comprehensive "308" Review Report on Columbia River and Tributaries by the Corps of Engineers.[5] Including non-Federal power, some 5,800,000 kw of installed capacity is presently existing, and about 3,400,000 kw is now under construction for a total of 9,200,000 kw. Eventual development of about 25,000,000 kw in the Columbia Basin within the United States appears practicable and economically feasible. In the referenced report it is estimated that a maximum capability of 36,700,000 kw in U. S. and 7,500,000 kw in the Canadian portions of the basin, totalling 44,200,000 kw, is theoretically possible. Actual development of this entire amount of power is neither economically feasible nor practicable of achievement because of high costs of many remaining developments and flowage problems due to present use of river valleys. Nevertheless the power potential of the Columbia River system ranks as one of the greatest resources of the Pacific Northwest, the more important because the region lacks other major energy sources such as coal, oil or natural gas.

In connection with the present primary dependence on water power, however, it is becoming generally realized among power engineers that increasing utilization of thermal power will be necessary in the future in order to maintain an economically balanced power generating system. At the present rate of load growth of about 400,000-500,000 kw per year, the readily available water power sites, and especially major run of the river projects and the most feasible storage sites, will be developed within the next 15 to 20 years. The necessity for increasing reliance on thermal power thereafter is apparent.

Hydro-electric Power Facilities at McNary Dam

The 980,000 kw installation at McNary Dam includes fourteen 70,000 kw main units and two 3,000 kw station service units, with space provisions for a possible future extension of the powerhouse to include six additional main units. The main power units are among the world's largest in physical size, having a runner diameter of 280 inches. Basic design of the powerhouse structure and generator facilities is generally similar to that of other recent major low head projects but surpasses previous accomplishments in many respects. Successful design, construction and operating experiences at Bonneville Dam and other similar projects, together with economic advantages inherent in size were incentives for development of units larger than any built previously. Limiting size of McNary power units was based in part on studies and information furnished by turbine and generator manufacturers at the time of preliminary design in 1946 which indicated the practical limit for total unit thrust to be about 4,000,000 pounds. This in conjunction with structural considerations in relation to width and depth of the unit monoliths established the economic size of units. Most features of the selected units are advancements beyond previous accomplishments. Achievements at McNary indicate still larger units may now be economical with thrusts of 5,000,000 apparently being feasible. Major features of the power facilities are briefly described below.

Powerhouse Structure

The powerhouse structure is founded on basalt and each unit is monolithic from the upstream face of the intake to the draft tube foundation exit, a distance of 248 feet. The height from lowest point of draft tube to intake deck is

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5. House Document No. 531, 81st Congress, 2nd Session.

about 185 feet. Overall length of the structure is 1422 feet and is made up of fourteen 86-foot main unit bays, an 86-foot station service bay and a 113-foot assembly bay. For typical section see Fig. 5. Three intake water passages serve each turbine scroll. The draft tube has a center pier which exceeds the normal design length due to space required for fish facilities above the draft tube.

Powerhouse Intake Gates

Three vertical tractor type gates 22 feet wide and 54 feet high weighing 180,000 pounds are provided for each of the 14 main power units. These gates have the skin plate placed on the upstream side and supported by horizontal and vertical diaphragms. The tractor rollers, pins and links are of corrosion-resisting steel. Each gate is operated with two vertical hydraulic cylinders pinned to the gate bottom and of a length approximately equal to the full height of the gate. The gates can also be operated by the 140-ton intake gantry crane provided primarily for maintenance. The 3 intake gates can be opened or closed simultaneously with the hydraulic system in about 4 minutes compared to 60 to 70 minutes required for gantry crane operation. The regular operating intake gates, 3 emergency gates and gate operating machinery cost approximately $4,500,000.

Hydraulic Turbines

The turbines supplied by S. Morgan Smith Co. are vertical shaft, single runner, adjustable 6-blade propeller type units of 280-inch diameter and 85.7 rpm rated at 111,300 hp under 80-foot head. The power rating corresponds to the generator continuous 115 percent overload rating of 80,500 kw. The turbines are designed to operate at heads ranging from 62 feet to 92 feet. The units are set low in relation to tailwater in order to develop the desired output at low heads within the allowable cavitation limits. The guaranteed efficiency at the 80-foot rated head is specified to be not less than 86 percent. Model tests indicate that turbine efficiencies up to 94 percent may be expected at best gate operation. Turbine characteristics indicated by model tests are illustrated in Figure 6 and installation views are shown in Figures 7 and 8. Model tests and field acceptance tests for the initial units indicate prototype operating efficiencies will be well above those required in the turbine specification. The high efficiencies are attributed to design refinements resulting from model tests and excellent workmanship. Model tests revealed that limiting the blade rotation to 16-1/2 degrees in lieu of the 6 degrees originally contemplated and modifying the shape of the blade tips increased the efficiency by about 0.5 to 1.0 percent under normal operating conditions due to the resulting smaller water passage at the blade tips. The total cost of the 14 main unit turbines as supplied by the manufacturer including supervision of erection will be about $21,700,000.

Generators

The generators are 73,684 kva, 85.7 rpm, 13,800 volt, 3-phase, 60 cycle, 84 pole generators with a name plate rating of 70,000 kw at 0.95 power factor. The units are capable of operating continuously at 115 percent of rated capacity. They are believed the largest in physical size of any generators made to date, with rotor assembly weight of 1,500,000 pounds. (Fig. 9). Rotor, turbine and hydraulic thrust will develop a total load of 4,013,000 lbs. on the thrust bearing. Generators for the first 12 units are being furnished by General

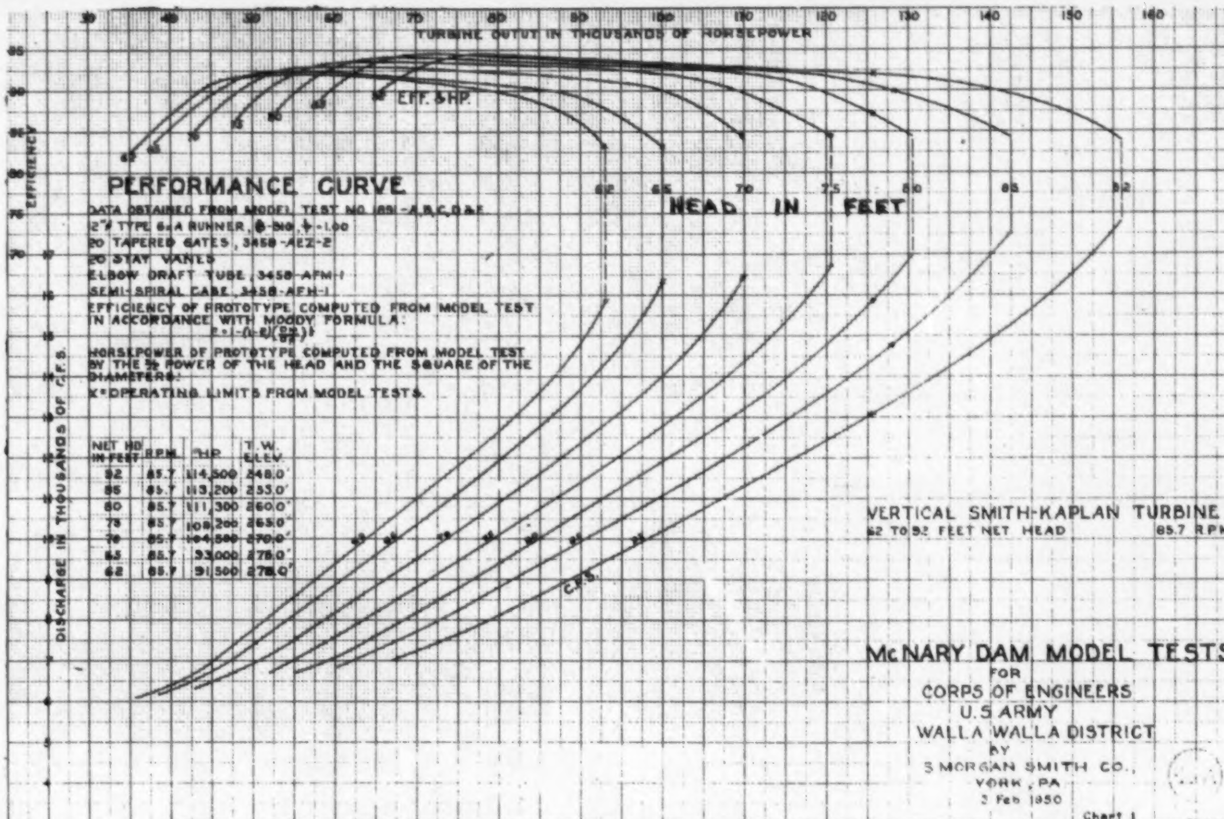

Figure 6 - Turbine characteristics

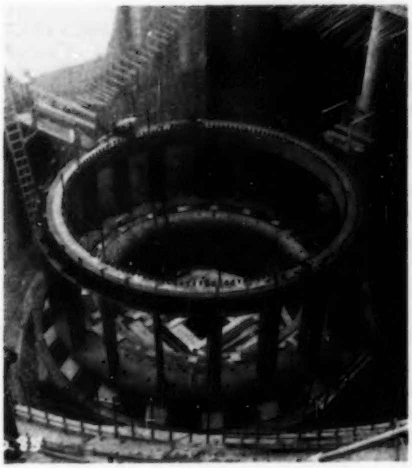

Figure 7 - Installation of speed ring

Figure 8 - Turbine runner assembly

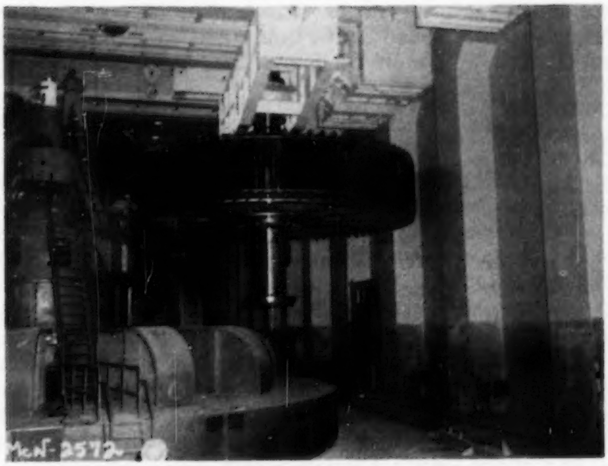

Figure 9 - Rotor assembly ready for installation.
Completed Unit No. 1 in foreground.

Electric Company and the remaining two units by English Electric Corp., marking the advent of foreign manufacturers into the supply field of large hydro-electric equipment in the United States. Total cost of furnishing and installing the 14 generators will be about $27,700,000.

Governors

Main unit governors furnished by Allis-Chalmers Manufacturing Co. and Woodward Governor Company at a cost of about $1,700,000 are oil pressure, relay valve, actuator type with electrically driven speed response elements. The governing equipment is arranged as "twin systems" permitting operation of either or both actuators for a pair of turbines from either or both sets of oil tanks and from either pump. Full turbine gate opening or closing can be adjusted for any rate between 5 seconds and 12 seconds.

Station Service Units

Two units each capable of supplying the normal plant load at minimum head are provided. The turbines are vertical shaft, single runner, Francis type units supplied by Pelton Water Wheel Co., rated at 4,500 hp for 80-foot head and 277 rpm. The generators are rated at 3,000 kw at 0.8 power factor, 3-phase, 60 cycle power at 4,160 volts, supplied by the Electric Machinery Manufacturing Company.

Powerhouse Bridge Cranes

Two overhead electrically operated bridge cranes of 350-ton capacity each are provided. One crane will handle the heaviest turbine assembly load of 690,000 pounds. Both cranes combined are required to lift the generator rotor, turbine and shaft assembly load of 715 tons. The maximum lift is 100 feet at a lift speed of 3 feet per minute. The bridge has a span of 78 feet, a run of 1,345 feet and travel speed of 100 fpm. The two cranes and lifting beams were supplied by Willamette Iron and Steel Company at a cost of about $335,000.

Transformers

The project electrical system is sectionalized, each pair of main unit generators being connected with a bank of three, single-phase, 56,500 kva transformers. Transformers are oil immersed, inert gas filled, forced oil cooled with forced water coolers. Transformers for Units 1 through 12 are 230 kv grounded Y to 13.8 delta kv and for units 13 and 14, 115 kv grounded Y to 13.8 delta kv. Weight of each is 268,000 pounds and oil capacity 7,700 gallons. Sixteen units were furnished by Moloney Electric Company, and six units by Ferranti Electric Company of England. Power is stepped up from 13,800 volts to 230,000 volts for generators No. 1 through 12, and to 115,000 volts for generators 13 and 14. The power from generators No. 1 through 12 is carried by five 230 kv circuits to a common bus at the nearby switchyard constructed by Bonneville Power Administration. Power from units 13 and 14 will be carried by a single 115 kv circuit to the switchyard, where it can serve the 230 kv bus through an auto-transformer.

Power Distribution

In common with other federal power developments in the region, McNary power output will be transmitted and marketed on a wholesale basis by the

Bonneville Power Administration of the Department of Interior. Seven transmission lines are now scheduled to carry power from the McNary switchyard to various Northwest load centers on the BPA system. Of notable interest is the fact that two of these lines are planned for operation at 300 kv with a maximum load capacity of 300,000 kw and a third line to the Portland-Vancouver area is scheduled for 345 kv and 400,000 kw load. Step up from 230 kv will be by auto-transformers at the switchyard. Eventual capacity of the seven lines will be approximately 1,640,000 kw, as compared to rated generator capacity of 980,000 kw and overload capacity of 1,127,000 kw at McNary power plant.

The 5,000 mile trunk line network of the Bonneville Power Administration now distributes some 3,000,000 kw from federal power dams to principal load centers in Oregon, Washington, and western Montana. About 3,000 miles of this system is operated at 230,000 volts, and forms the backbone for major power transmission in the region. The Administration is a member of the Northwest Power Pool, which includes in its membership practically all private as well as public power systems in the entire region, and serves to integrate these individual units into a single vast system covering the entire Northwest. This power pool, with interconnections as remote as eastern Montana, Idaho, Utah and British Columbia, has increased the firm capacity of the system by about 700,000 kw or 10 percent of the approximately 7,000,000 kw effective interconnected power generating capacity.

Fish Passage Facilities

Greatly complicating the planning and construction of works for control and utilization of Columbia River waters is the fact that this stream is one of the greatest fish producing rivers in the world. Preservation of this resource is a basic requirement. The value at producer levels of the commercial products of the Columbia River fisheries has been estimated at $17,500,000 annually, and its sports fishery has national renown. These activities are supported and maintained by migratory fish populations which use the Columbia River and tributaries for migration lanes and spawning. Of these anadromous fish the chinook salmon is of greatest commercial importance with bluebacks and silver salmon also making an important contribution to the fishery. Steelhead trout (similar to the Atlantic Salmon) contribute to the commercial catch but the main value of this species relates to sport fishing. Development of streams in the Columbia Basin for navigation, irrigation, flood control, hydro-electric power and other uses to provide for the expanding economy of the Pacific Northwest has imposed and continues to impose major problems relating to the maintenance of anadromous fish populations. Maintenance of existing fish life is vital to both commercial and sport fishery and large expenditures approximating ten percent of total project costs, have been made at Bonneville and McNary Dams for fish passage facilities. There is no indication that Bonneville Dam in its 15 years of operation has been detrimental in the passage of fish, and it is not anticipated that McNary will be detrimental. It is recognized, however, that with the advent of several more dams, additional research and factual data will be necessary to determine more definitely the actual requirements for economic design for adequate passage facilities.

Fish passage facilities provided at McNary Dam at an aggregate cost of $27,000,000 (Fig. 10 and 11) include a fishladder and a gravity fishlock on the Washington shore; a pressure fishlock between the spillway and the powerhouse; a fishladder and provisions for a future gravity fishlock on the Oregon

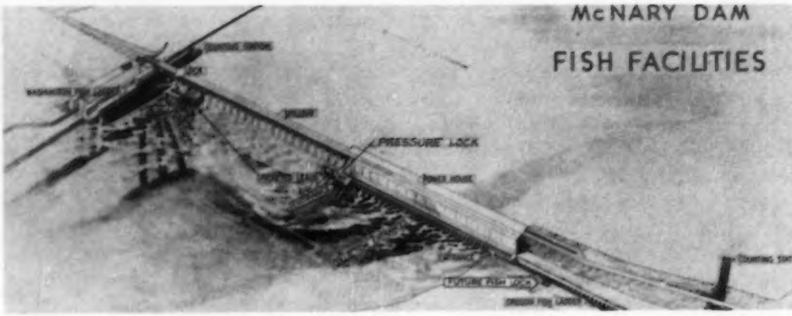

Figure 10

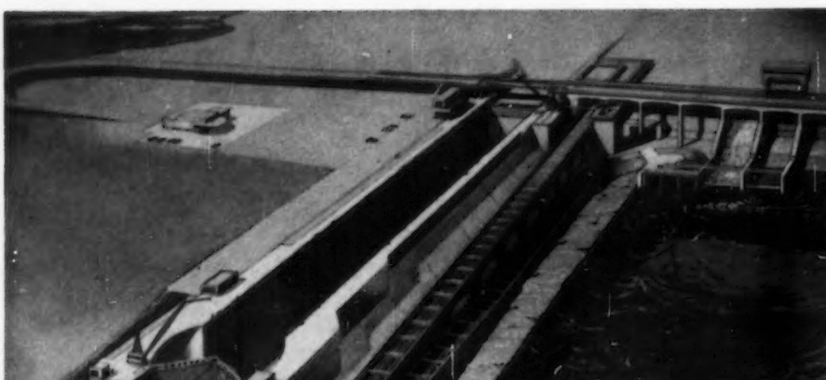

Figure 11

shore; a powerhouse fish collecting system which, together with a major central fish entrance bay between the spillway and powerhouse and a similar entrance on the Oregon shore, connect with the Oregon fishladder; and a pump house with distribution system for auxiliary attraction water supply. The fishladders, collection system and gravity fishlock are adapted from the Bonneville facilities as modified by extensive model testing and study of Bonneville operation with resulting improvements in design details and operational control. The pressure fishlock, primarily for experimental purposes, is an innovation which holds considerable promise of successfully replacing conventional fishladders in future dams at a major saving in costs.

Each fishladder is 30 feet wide with a floor slope of 1 vertical to 20 horizontal and an overall length of about 2,000 feet. Pool lengths are 20 feet with concrete weirs 6 feet in height providing a drop of 1 foot between successive pools. Two submerged orifices are provided in each weir. The total flow down each ladder is from about 125 to 220 c.f.s. with additional flows varying from about 900 to 2,800 c.f.s. on the Washington shore and 4,500 to 7,200 c.f.s. on the Oregon side, dependent on river discharge and tailwater elevations, all added through auxiliary supply conduits in the lower reaches of each ladder and at fishway entrances for attraction. These flow requirements are based on the instincts of the fish to seek flowing water in their upstream journey.

The powerhouse collecting system consists of a channel 17.5 feet wide extending the full length of the powerhouse over the draft tubes, with 44 evenly spaced automatically operated telescoping entrance gates on the tailrace side each 10 feet wide. These gates are so designed that they may be operated as overflow weirs or as submerged orifices, to facilitate entrance of fish into the channel.

The Washington shore gravity fishlock is similar in principle to a navigation lock. It has a 20 by 30 foot vertical chamber 118 feet in height providing a hydraulic lift of 85 feet. After the fish enter the lower level, the water in the lock is raised to forebay level. A submerged grill sloping toward the pool rises beneath the fish as the water level is raised to force them toward the upper exit gate. The pressure fishlock is essentially a horizontal pressure conduit with entrance below tailwater elevation and exit deep in the reservoir. The pressure chamber is provided with appropriate gates and fish are locked through, under reservoir pressure, with exits from the chamber based on a flow of water and the urge of the fish to seek lesser pressures. Operating tests will be conducted in the near future to determine the effectiveness of this simple and economical facility.

Due to rigid flow requirements established by the fishery agencies many complicated hydraulic, structural, mechanical and electrical control problems are associated with the fish collection and ladder facilities. One of the major engineering problems was to provide up to a maximum of approximately 7,000 cubic feet per second of flow in addition to that flow coming down the Oregon shore fishladder for the purpose of maintaining uniform flow in the lower reaches of the ladder, fishway channels and powerhouse fishway entrances and adequate attraction flows under variable tailwater conditions. Generally this flow was required for dispersed interjection throughout the floor system of the fishways at a net head of about one foot above tailwater. Preliminary construction plans were predicated on a much smaller requirement to be provided by gravity flow from the reservoir. However, the increased supply was found necessary upon more detailed studies and this method would have involved varying energy dissipation up to approximately 50,000 horsepower. Supply of the total volume by gravity flow proved impracticable from either an

economical or engineering viewpoint. In fact, with the space limitations present, no method was found that would provide satisfactory energy dissipation and exit flow conditions. Extensive investigations accordingly were necessitated to determine a practical method of providing supplemental fishway water supply. The following alternate basic methods of supply were considered:

a) Gravity supply from the reservoir, eliminated as impracticable.

b) Supply from reservoir through a hydro-electric power turbine unit discharging into the supplemental water distribution system, theoretically accomplished either (1) by a special power unit or units designed specifically for that purpose, or (2) by adaptation of one or more main units. Due to the stage of project construction existing at the time of the studies it was found impractical to adopt this method. However, model studies were performed which proved the feasibility of the method. As a result of these studies special turbine and generator power units tailored to meet supplemental water requirements for fishway collection systems are being incorporated in The Dalles project and in the design of the Lower Snake River projects with anticipated savings of millions of dollars in fish facility construction and operational costs.

c) Pumping from tailwater. This method was found practicable from engineering, construction and maintenance viewpoints and was adopted at McNary. Preliminary design investigations resulted in the selection of pumps unprecedented in size. Three Kaplan type, adjustable 3-blade pumps of 2,500 c.f.s. capacity each were selected. Two pumps meet normal requirements of 4,200 to 5,000 c.f.s. The third pump is required to furnish about 1,000 c.f.s. additional flow during high river stages and provides standby service at other times. The total cost of the pumping plant is about $3,000,000.

Spillway

McNary spillway has a flow capacity of 1,368,000 c.f.s. at normal pool elevation 340 and 2,200,000 c.f.s. at maximum surcharge pool elevation 356.6. As compared to these capacities, the maximum flood of record was 1,200,000 c.f.s. The structure consists of 22 - 50-foot bays separated by 21 - 10-foot wide piers resulting in an overall length of 1310 feet. The crest elevation is 291 with flows controlled by split-leaf, vertical lift type gates 50 by 53 feet. The stilling basin floor is 270 feet in length, with floor level at elevation 228.0. Two rows of vertical-faced baffles 10.5 feet high by 10.0 feet wide are located in staggered arrangement at 20-foot centers. The two rows are located with their upstream faces at 90 and 135 feet upstream respectively from the vertical face of the terminal sill. A typical section of the spillway is shown on Figure 5.

Gate leaves are split or sectionalized at the center, permitting discharge by raising the upper portion, thus facilitating the safe passage downstream of fingerling fish. The lower section of each gate is articulated in order that the large water load may be evenly distributed over each series of two wheels of the six wheels required for each side of the section. Two 200-ton gantry cranes are provided for gate operation. Each crane is capable of lifting an entire gate assembly weighing 170 tons at a rate of 4 feet per minute. The crane travel speed along the deck is 120 feet per minute and the crane trolley speed is 20 feet per minute. A complete single gate closing or opening operation by the gantry crane requires 20 to 30 minutes. The spillway gantry cranes are served by a roadway and railroad spur on both the Washington and

Oregon shores and, if needed, by the powerhouse intake gantry cranes. Gate maintenance pits are provided below deck in the non-overflow section adjacent to the navigation lock.

Preliminary investigations contemplated use of split-radial gates. Hydraulic model studies of alternate designs, however, showed that considerable difficulty would be encountered with such gates in preventing the flow between gate sections from impinging on the trunion arms. The tests also indicated that protective plates around the trunion arms would be subject to side thrust and negative pressure to the extent that structural design against vibrational forces would be complicated and expensive. These factors, together with erection problems involved in the unprecedented size of gates required and in the requirement for passing river flow over the spillway during construction, contributed to decision to use the split vertical lift gate.

Hydraulic design of the vertical lift gate is particularly concerned with the bottom shape of both the upper and lower gate sections and with the top of the lower gate section as discharge will occur either beneath the lower gate section or between the gate sections. Aeration is provided underneath the nappe for discharge between the gate sections by two 24-inch air vents in the piers for each gate. As serious cavitation of the crest and side of piers downstream from the gate slots had been experienced with somewhat similar gates at Bonneville Dam, particular attention was given this problem in hydraulic model tests. As a result of these tests the slots were streamlined and the downstream corners were offset approximately 1/8 of the slot width to eliminate most of the negative pressures. Armoring of the critical area downstream from the gate slots has also been provided.

Embankments, Levees and Relocations

Earth Fill Abutment Sections

More than half the length of McNary Dam is comprised of earth and rock embankments. The Washington shore embankment is 1,620 feet long between the navigation lock and north abutment, and the Oregon shore embankment extends 2,465 feet from the powerhouse to the south abutment. The maximum height of both fills is approximately 100 feet and the crest width is 30 feet. The embankments consist of a relatively narrow rolled impervious core extending to bed rock and a rock fill shell. Slopes are 1 on 1.5 upstream and vary from 1 on 1.32 to 1 on 2.5 downstream, and are protected by select rock revetment. Closely controlled filters provide a transition between the impervious core and the shells. A major problem in design was occasioned by the open nature of the gravel in the foundation of the Oregon abutment, where a blanket has been provided extending about 1,000 feet upstream and a drain installed downstream for seepage control.

Levees

The cities of Pasco, Kennewick and Richland, Washington, with a total population in excess of 50,000 are located on the banks of Columbia River along the upper reaches of the reservoir area. These cities and nearby densely populated or valuable farm areas which would be subject to flooding induced by the reservoir have been protected by a system of levees. This levee system is notable particularly for the extensive provisions necessary to cut off underground seepage for depths as great as 70 feet. Generally it might be said that a major portion of these levees are underground.

In Richland and vicinity 3.2 miles of levees with drainage facilities including two pumping plants were constructed; in Kennewick and vicinity 8.6 miles of levees and seven pumping plants were constructed; and, in Pasco and vicinity 5 miles of levee and six pumping plants. The total capacity of all pumping plants is 245,000 gallons per minute. In conjunction with the levees, there are approximately 21 miles of interceptor ditches to collect reservoir seepage water, irrigation waste and storm run-off from landward sources. Levees vary in height above ground from 2 to 30 feet and provide protection against backwater from the maximum recorded flood of 1894 with 8 feet of freeboard for urban areas and 5 feet elsewhere. The levees generally consist of an impervious core, pervious shells, and 12-inch quarry stone revetment on the riverward side. The foundations vary considerably but on the most part consist of 2 to 10 feet of silt overlying 10 to 40 feet of extremely pervious gravel, which in turn rests on a shale-like clay or on basalt bed rock. Preliminary design studies indicated that an impervious cut-off through the gravel was necessary to avoid prohibitive costs for pumping seepage, enable satisfactory control of the interior water table and to insure stability at the landward toe of the levee. Since most of the cut-off was below water table, excavation of the trench presented serious construction difficulties. One of the contractors chose to excavate in the dry, using pumps to keep the water down in the short sections of open ditch, while another contractor chose the option of using a bentonite slurry in the ditch to prevent caving during excavation and backfill. The latter method allowed maintenance of essentially vertical side slopes in the cut, greatly decreasing the amounts of excavation and backfill but increasing digging difficulties. The methods had approximately equal costs per lineal foot of cut-off but the second method has advantages when right-of-way is limited and where depths do not exceed about 30 feet. Backfill for the cut-off was a well graded mixture of gravel, sand and silt to ensure minimum settlement and permeability, together with most economical use of available materials. The one year experience since the reservoir was raised to normal pool indicates that general design was adequate and reasonably accurate insofar as stability and ground water control is concerned. However in the few short reaches where no cut-off was provided, difficulties are occurring in water control at the landward toe and corrective measures have been required.

Relocations

Relocation of existing transportation, communication and utility facilities essential to development of the McNary project was a major program totalling over 41 million dollars in cost. This work included relocation of 31.7 miles of state highways, 10.8 miles of county roads, 40.6 miles of power lines, 83 miles of telephone and telegraph lines and 80.8 miles of railroads. The railroad relocations involved 40.5 miles of Spokane, Portland, and Seattle Railway trackage; 23.7 miles of Union Pacific Railroad trackage; and, 11 miles of Union Pacific-Northern Pacific joint trackage and at the time comprised the largest railroad construction program in the United States. Daily rail traffic averaging four passenger and two freight trains on the Washington shore S.P. and S. line and two passenger and two freight trains on the Oregon shore Union Pacific line was maintained on these lines throughout construction in the face of unusual engineering and construction problems. The relocations were constructed for the most part between the narrow confining limits of high rock bluffs and steep talus slides on one side and the existing railroad and river on the other. Existence of an inter-state highway paralleling the Union Pacific tracks along the left bank through the narrow gorge below Wallula Gap further

complicated the relocation problem to the extent that it was found essential to close this major highway for a period of about one year. It was necessary to bench into the talus slopes which consisted of loose rock and geological debris up to 600 feet high, and to remove huge quantities in order to maintain stable slopes. Cuts through solid rock up to 100 feet in height were common. Additional complications arose from the existence of extensive areas of wind-deposited silts and volcanic ash which were so light and unconsolidated that they would lose much of their supporting power when inundated by the rising reservoir. To assure safety of the railroad bed, it was considered necessary to excavate much of these unstable materials and replace with rock or gravel or otherwise treat foundations and embankments to assure stability. In many locations the excavation was carried 40 to 50 feet below the finished road bed. Railroad station and a major portion of the switchyards at Wallula, Washington, which were in the reservoir area were moved to Hinkle, Oregon. The inhabitants of this small railroad town moved to a higher location nearby overlooking the new reservoir.

Reservoir

In contrast to a naturally occurring 35-foot variation in river stage between extremes of observed discharges, McNary pool level will be relatively stable, with a maximum drawdown of 5 feet at the dam. Thus there is created a major lake having a shore line length of 242 miles, a surface area of 38,800 acres and reach of 60 miles along Columbia River and 10 miles along Snake River. Power pondage of 185,000 acre-feet available in the upper five feet also has some minor flood control value under certain conditions. About 18,000 acres of shore line lands were acquired for the project since a major portion of the reservoir is closely traversed by relocated railroads and highways, and considerable portions of other adjacent lands are subject to erosion or inundation during flood periods. However, acquisition of inundated and shore lands was limited to areas essential to project construction and operation.

Reservoir Planning, Development and Management

The most effective public use of the reservoir and its shore lands has been the subject of careful studies. Controlling criteria were developed on a reservoir management plan based on the policy of providing the greatest sustained benefit to the public with full consideration to project operation, industrial, public and quasi-public recreation and fish and wildlife use. Public hearings, informal meetings, and extensive studies in coordination with the many diverse public agencies and private interests concerned preceded formulation of this plan. In all these matters the Corps has acted primarily in a coordinating capacity to the end of resolving and adjusting the many diverse requirements into an equitable overall plan. Specific areas have been designated for industrial development dependent on suitability of the land, rail and waterborne transportation, power supply, and water supply. Already two major oil terminals have been established, grain shipping terminals have been expanded, and construction initiated on a $12,000,000 fertilizer plant. Other lands are reserved for port facilities to serve tributary areas including the cities of Umatilla and Pendleton, Oregon; and Walla Walla, Pasco, and Kennewick, Washington. Plans for development of these facilities are rapidly taking place.

Public Use

A policy of delegating a maximum of responsibilities for recreational, wildlife and other public use functions to state and local agencies has been followed. Water related recreation and fish and wildlife activities will be major features of public use of the reservoir and its shores since the region is markedly deficient in public water areas supporting activities of this type. Licenses have already been granted covering three state wildlife management areas, three state park areas, two county park areas, two city park areas and two juvenile fishing areas. Development has been initiated in all but one of these areas and is well advanced in two park areas and two wildlife areas. A cooperative agreement is in process and development is well advanced on one national wildlife management area. Large land and water areas under state management will be open to public hunting—an opportunity not heretofore available along Columbia or Snake Rivers and new spiny-rayed fishing areas have been provided. All of this development by state and local agencies is logical, since the benefits to be derived are largely local in nature.

Appropriate areas are also provided for social groups, semi-private, and private organizations for development in connection with youth group activities, boat clubs, and fraternal organizations. Extensive use is anticipated from these types of activity that will derive much benefit from the project and tend to stimulate other public uses of the area.

The extensive cooperative efforts of many local interests and careful planning with them has made possible the development of a Master Plan to coordinate project operation, navigation, reservoir access, health hazards, debris control, and public and private use of McNary Reservoir which represents an outstanding achievement toward optimum utilization of this resource.

Construction

Construction Schedule and Present Status

McNary project was authorized in 1945, construction funds were appropriated in Fiscal Year 1947, and construction was initiated in May 1947. At that time the construction schedule provided for raising of the pool to be accomplished by November 1954, generation of power with the first unit in December 1954 and completion by December 1958. The first phases of construction of the Washington shore included railroad relocation, construction of the first step (Washington shore) cofferdam, navigation lock and 13-1/2 bays of the 22 bay spillway except for the upper portions of the spillway ogee sections (Figure 12). The cofferdam was designed to withstand a flow of 700,000 c.f.s. estimated to have a frequency of once in 5 years in anticipation of protecting the enclosed construction and allowing construction to continue during the flood season. In May 1948 the cofferdam was overtopped by a flood of 980,000 c.f.s. the second largest of record and previously exceeded only by the 1894 flood. However, relatively minor damage was done, and the time lost during the time the cofferdam was flooded and during repair and clean-up operations was later made up.

In 1948 it was determined that due to the national emergency and expected shortage of power in the Pacific Northwest it was essential to advance the date for initial power generation of the first unit by one year (to December 1953) and placement of each successive unit into commercial generation every three months, thus advancing final completion of the project two years (to December 1956). To achieve this goal an intermediate construction phase

previously planned to be a part of phase two construction was initiated. This work consisted of a "Junior" cofferdam constructed against the Oregon shore within the limits of the second-step cofferdam but preceding that structure in time sequence. This cofferdam inclosed a portion of the left abutment, fish passage facilities, including the supplemental fish attraction water pumping plant, and part of the powerhouse consisting of the assembly bay, station service units and the first two main units. (Fig. 15.) The "Junior" cofferdam was designed for a flow of 750,000 c.f.s. and enabled operations to be initiated at an early stage on the time consuming powerhouse construction, thereby achieving the expedition of initial generation by one year. Contracts already awarded for equipment were modified to provide for installation of units at intervals of 90 days each in lieu of 120 days as previously scheduled and future contracts and construction schedules were adjusted accordingly, which also made possible completion by December 1956.

River Closure

Closure of the second-step cofferdam was a major step in harnessing the mighty Columbia at McNary. This phase presented a very difficult engineering and construction problem which was solved by an ingenious method used for the first time on a major river closure. The achievement invites application of the McNary method to difficult diversion problems on future projects and provides a full scale model experiment for a somewhat similar closure of the main stream proposed in the near future at The Dalles Dam.

Figures 13 and 15 show the general layout of the second-step cofferdam and the location of the 240-foot gap in the Oregon channel for which closure had to be made. The navigation lock and the 13-1/2 spillway bays on the Washington side were constructed with the ogees in the first 12-1/2 bays concreted to elevation 250, or 41 feet below the ultimate crest in order to permit river diversion over the uncompleted spillway.

The time available for completion of the closure was limited to less than 60 days before probable occurrence of winter storms, due to the necessity for leaving an unobstructed passageway until October 10 for the upstream migration of fall run chinook salmon. Such storms could be expected to result in river flows in excess of the 150,000 c.f.s. considered as the upper limit for feasible closure operations by the method selected.

Prior to closure the entire river flowed through a narrow gap only 50 feet in width at the bottom and 240 feet in width at the water surface. River soundings showed that the floor of the gap to be closed consisted of two rock shelves with a deep trough between having a maximum depth of 53 feet at low water. The severe combination of great water depth, large river discharges, high velocities and limited time available coupled with the requirement that the closure had to raise the river water level 17 feet before all the river flow could be forced through the low spillway bays, made the operation one of the most difficult river diversions encountered in construction history.

The closure was accomplished by placement of 2,088 twelve-ton concrete tetrahedrons and approximately 28,000 tons of stone with minimum weight of 1-ton and 45,000 tons of rock spalls in alternate zones and lifts. The materials were placed by dumping from a cable supported skip. Both cable towers were movable to facilitate spotting of materials at any desired location (Figure 13). The tetrahedron and rock fill closure was brought above water after a total of 37 days of placing operations which included a 16-day delay due to construction difficulties on other work on the cofferdam, thus diverting the river flow through the low spillway bays. River flows during the closure

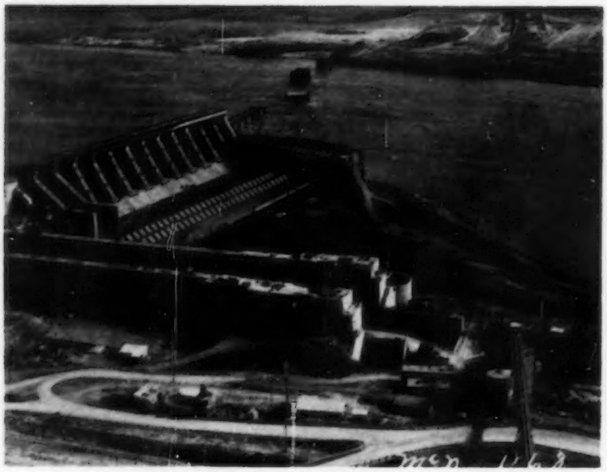

Figure 12 - First stage construction, Washington shore navigation lock and 13-1/2 spillway bays in foreground. 6 March 1950

Figure 13 - "Second-step" Cofferdam constriction prior to closure Note "field" of tetrahedrons in Oregon shore foreground and movable cable towers for placing. 18 October 1950

Figure 14 - "Second Step" Cofferdam closure
at effective completion of tetrahedron fill. 27 November 1950

Figure 15 - "Second Step" Cofferdam completed. Oregon shore
"Junior" cofferdam and construction of assembly bay, station service
bay and main unit bays 1 and 2 of powerhouse in foreground. 4 January 1951

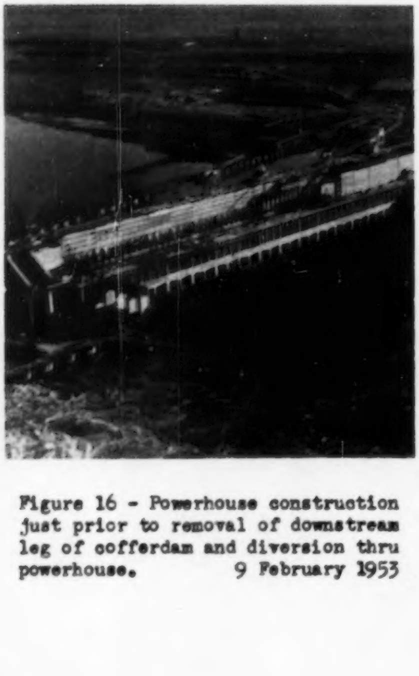

Figure 16 - Powerhouse construction just prior to removal of downstream leg of cofferdam and diversion thru powerhouse. 9 February 1953

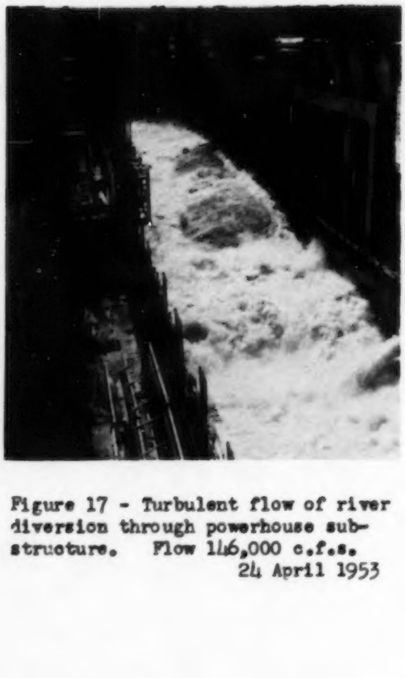

Figure 17 - Turbulent flow of river diversion through powerhouse substructure. Flow 146,000 c.f.s. 24 April 1953

varied from 96,000 to 157,000 c.f.s. with a flow of 111,000 c.f.s at the time closure emergency (Figure 14). Approximately 12,000 c.f.s. flowed through the voids in the closure fill prior to placing the upstream filters, impervious blanket and protective courses. Following completion of the closure section, the downstream leg of the cofferdam was constructed (Fig. 15) and the enclosed area pumped out. Construction thereafter progressed rapidly on the removal of the "Junior Cofferdam", powerhouse excavation and construction of the powerhouse substructure until overtopping of the cofferdam occurred in early June. At this time the river flow exceeded 370,000 c.f.s. which had been determined to be the economical design limit for the second-step cofferdam. Powerhouse construction in the assembly bay, station service units, and main units 1 through 4 continued uninterrupted, however, as these units were protected by strategically located bulkheads, gates and stop logs.

Third stage construction included cofferdam removal, raising of the ogee sections of 12-1/2 spillway bays, completion of the upper lock sill, completion of the powerhouse and raising of the pool. After construction of the powerhouse intake structure, draft tubes and substructure (Fig. 16), the second-step cofferdam was removed and the ogee sections of the 12-1/2 spillway bays were raised to crest elevation. During this operation diversion of the entire river's flow was through powerhouse units 5 to 14, in which construction had advanced to the roof line of the scroll case and piers between units. This diversion probably represented the greatest flow ever passed through a powerhouse substructure, the maximum flow being 146,000 c.f.s. (Fig. 17).

Upon completion of the ogee sections the powerhouse intake gates were closed to raise the pool to an intermediate elevation 310, thereby, again passing the river's flows through the spillway thus achieving the last phase of river diversion and the initial phase of permanent raising of the reservoir level. Final raising of the reservoir to its permanent level was accomplished after completion of the blockout section in the navigation lock upper miter sill, installation of the upper lock gate (a temporary low level upper lock gate in a blockout section was used to maintain navigation throughout nearly the entire period of second and third phase construction), completion of permanent fish passage facilities to a stage at which they were operable, and completion of relocations and land acquisition. The pool was raised to elevation 335 on November 4, 1953 and to elevation 340 in December.

Construction quantities and costs reflect the magnitude of the construction program. Approximate quantities of major items are summarized below.

Excavation, all classes	4,075,000 cu. yd.
Concrete	1,880,000 cu. yd.
Steel, Structural and miscellaneous	26,000,000 lb.
Pipe, handrailing, etc.	2,670,000 lb.
Reinforcing	108,740,000 lb.
Machinery	53,000,000 lb.

Estimated project costs as of July 1954 by major features is illustrated in the following summary:

Feature		Construction cost
Lands and damages		$ 10,707,000
Relocations		40,701,000
Reservoir		745,000
Dam		32,533,000
Spillway dam	$19,500,000	
Non-overflow	8,133,000	
Earth fill abutments	4,900,000	
Lock		20,610,000
Fish facilities		27,029,000
Power plant		140,009,000
Roads and railroads (access)		526,000
Levees and pumping plants		11,235,000
Recreation facilities		145,000
Buildings, grounds and utilities		2,290,000
Permanent operating equipment		770,000
Total		$ 287,300,000

Project Economics

McNary project will have far reaching effects on the entire economy of the Pacific Northwest. These benefits will be achieved almost entirely on a self liquidating basis, inasmuch as power revenues derived from operation of this project in the Northwest Regional System will be adequate to more than repay all costs connected therewith. The major non-self liquidating cost will be that associated with the navigation feature amounting to about 7-1/2 percent of the project cost which feature has been traditionally underwritten by the Federal Government as a national policy. Benefits resulting from individual features of the project are discussed briefly below.

Navigation Benefits

As an essential unit in the navigational development program of lower Columbia and lower Snake Rivers it is estimated that McNary Lock and Reservoir pool will serve an average annual movement of 3,600,000 tons of commerce. The average annual benefits associated with this commerce, based on savings in transportation costs, are estimated at $1,081,000 annually.

Power Benefits

Firm power generation at McNary is estimated at 654,000 kw of average continuous power during the critical low flow power period (5,729,000 kwh annually), or 969,000 kw of firm power at 75% load factor in the intermediate phase of Basin Development (Phase C level as presented in House Document 531). No monetary value is credited to the average annual secondary energy generation of approximately 1 billion kwh, although such power is now nearly

100 percent salable. The annual firm power benefits alone are estimated at $20,951,000 totalling over 1 billion dollars through the assumed 50-year economic life of the project, nearly 400 million dollars over and above the total of the annual costs during this period.

Irrigation and Incidental Benefits

Creation of the reservoir pool is expected to benefit development of over 244,000 acres of nearby irrigable lands by reduction in pumping costs and pipeline construction. Estimated benefits averaging $306,000 annually are considered incidental to the primary purposes as are public use, recreational and wildlife benefits estimated at $61,000 annually. Such incidental benefits are not included in cost allocations.

Economics and Allocations of Costs

On an annual basis the overall benefit to cost ratio of the project is 1.44 to 1, taking into account the above benefits and all direct and indirect costs chargeable to the project. On a first cost basis approximately 92% of total cost is tentatively allocated to power and 8% to navigation, subject to reconsideration and revision when final data are available. An interim allocation was made by the Federal Power Commission in 1953 based on actual and estimated construction costs as of 1 July 1953. Specific separable costs for the inclusion of power, navigation and recreation facilities in the project were allocated directly to those purposes. Of the remaining costs, designated as joint-use costs, 97.5 percent were allocated to power and 2.5 percent to navigation.

CONCLUSION

Construction of the McNary project has again demonstrated capabilities and resourcefulness of American construction and manufacturing industry. This has been particularly exemplified by the major contractor on the dam, the Atkinson-Ostrander-Jones Co. who has shown great ingenuity and aggressiveness in overcoming major obstacles and adverse conditions in coping with the unpredictable Columbia River to meet a well-nigh impossible schedule. The American power equipment manufacturing companies as exemplified by General Electric Co., S. Morgan Smith Co., and others have made notable advances in the design, manufacture and installation of power units of unprecedented size, with results exceeding specified requirements of time as well as performance. Many other contractors and suppliers, whether or not specifically mentioned herein have likewise accomplished outstanding results and without exception cooperated closely with the Corps of Engineers in achieving scheduled completion of the project.

The basic design was conceived and developed by the Portland District, Corps of Engineers under the then District Engineer Col. O. E. Walsh. Since November 1948, design and construction of the project has been carried on by the Walla Walla District under the successive leaderships of Col. William Whipple, Jr., Col. William H. Mills, Col. F. S. Tandy and Col. A. H. Miller, present incumbent. Both districts operate under general supervision of Col. Louis H. Foote, Division Engineer, North Pacific Division, with headquarters at Portland, Oregon, and general direction of Major General Samuel D. Sturgis, Chief of Engineers, Washington, D. C. Valuable contributions to the preparation of this paper have been made by Mr. Edwin C. Franzen, Chief, Engineering Division of the Walla Walla District and other members of the staff.

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.